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(71) Applicants and
(72) Inventors: **SHEEHY, Timothy** [US/US]; 4760 State Route 38 N., London, OH 43140 (US). **BALES, Andrew, J.** [US/US]; 130 East Bell Court, Lexington, KY 40508 (US).

(74) Agent: **OLDACH, William, H., III**; Vorys, Sater, Seymour and Pease LLP, 1828 L Street, NW, Suite 1111, Washington, DC 20036-5109 (US).

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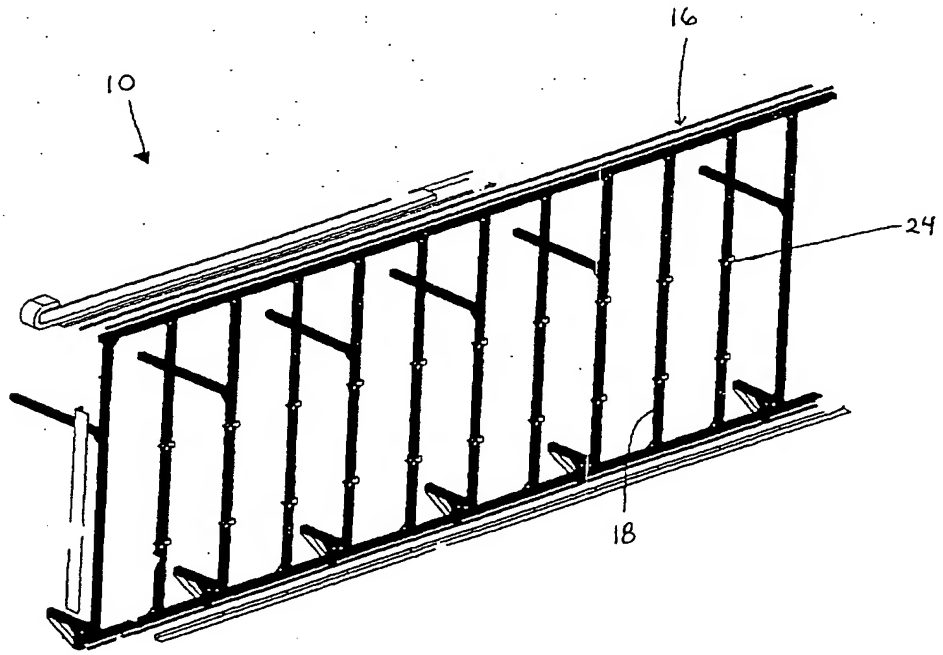

(57) Abstract: A system and method are provided for the automated painting of workpieces, such as signs. In a preferred embodiment, the system (10) comprises a CNC- controlled gantry-style robot (14) that traverses a support structure (16) with a sprayer head that moves about six axes, including three axes of rotation, to allow reliable point coverage of the workpiece, even if the workpiece has an embossed, three-dimensional surface.

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AUTOMATED PAINTING SYSTEM AND RELATED METHODS

This application claims the benefit of United States Provisional Application Serial No. 60/328,635, filed 11 October 2001, the full disclosure of which, including drawings, is incorporated as if fully set forth herein.

Technical Field

The present invention relates generally to the art of computer-controlled devices and, more particularly, to a computer numerically controlled (CNC) multiple-axis painting device and a related method for painting a workpiece, such as a sign.

Background of the Invention

The process of hand painting a workpiece, such as for example a sign for conveying information to the public, is often a laborious and expensive undertaking, especially in cases where multiple colors are required, complex patterns are desired, or in mass production situations. Current automated sign painting techniques often require significant manual input and interaction by an operator for tasks such as indicating areas which are not to be painted, for changing the paint supply to switch from one color to another, or the like. Additionally, often several machines are required to complete the desired painting tasks on a particular workpiece, such as a complex, multicolor sign using different hatch or fill patterns. The operation is particularly daunting in the case of an embossed workpiece, where paint must be applied essentially to a three-dimensional surface rather than merely a two-dimensional, flat area. Accordingly, a need is identified for an improved system and method for painting a workpiece such as a sign in an automated fashion to reduce the amount of labor and manual input by personnel and still achieve a high-quality finished product.

Computer numerically controlled (CNC) devices are currently used for a variety of automated machining applications, including lathes, milling machines, cutting devices, welders, and the like. The typical CNC machine is controlled by a computer that is pre-programmed by the user with a series of instructions required to perform a particular sequence of movements or tasks (such as based on the particular location where each operation is to be performed, usually expressed in Cartesian coordinates). With the advent of improved robotics and sophisticated computer

technology, modem CNC machines capable of highly complex multi-step operations have evolved.

Summary of the Invention

In one aspect, the present invention adapts CNC technology to the tasks and movements required for painting a workpiece, such as a sign. The result is the painting may be achieved in a more expeditious and efficient manner and, hence, at a lower cost, even where the design is complex or in the case of a workpiece including embossments.

In another aspect, the invention comprises an automated painting system. In a preferred embodiment, the painting system of this invention comprises a CNC controlled gantry-style robot that is capable of moving a sprayer head relative to at least one, and preferably six axes for applying one or more colors of paint to selected surfaces of a workpiece, such as a sign. A support structure for retaining the workpiece in place while paint is applied by the multiple-axis sprayer head may also be provided as part of the system.

In still another aspect, the present invention comprises an automated method for painting a workpiece, such as a sign. The method of the present invention allows for the efficient and reliable painting of complex designs, regardless of whether the workpiece includes a substantially planar two-dimensional surface or an embossed, three-dimensional surface.

In yet another aspect, the present invention provides a method and system for determining the positioning of a workpiece relative to a sprayer head of a CNC controlled painting device, as well as a method and system for calibrating the positioning of the sprayer head relative to the workpiece. Proper calibration and positioning allows for the more precise application of paint at desired locations along the workpiece in accordance with a preprogrammed instructions, also known as a "digital job." Consequently, painting even the most complex designs in an efficient and reliable manner is possible with limited manual user input or intervention during the painting operation.

Additional aspects, advantages and other novel features of the invention will be set forth in part in the description that follows and in part will become apparent to those skilled in the art upon examination of the foregoing, or may be learned with the practice of the invention.

Detailed Description of the Invention

Reference is now made to Figures 1-6. In one aspect, the present invention provides a computer numerically controlled (CNC) painting system 10 for painting a workpiece such as a sign. In a presently preferred embodiment, as depicted in Figures 1a and 1b, the CNC painting system 10 comprises: (1) a gantry-style robot, including a sprayer head 12 including: (a) at least one, and preferably a plurality of spray nozzles 12a; and (b) a movable gantry 14; and (2) a workpiece support structure 16. As will be outlined further in the description that follows, the robot in the illustrated embodiment includes a plurality of motive devices that are capable or moving the sprayer head 12 relative to the workpiece in up to six different axes.

The workpiece support structure 16 may be substantially rectangular in shape, with at least one, and preferably a plurality of struts 18 for supporting a workpiece (not shown). The structure 16 may further include at least one ground-engaging member 20 and at least one support rail 22 for determining the angle at which the workpiece is maintained. The details of the construction of one possible support structure 16 are shown in Figures 1a and 1b (note preferred angular positioning in Figure 1b).

The workpiece support structure 16 further includes at least one device for affixing a workpiece in substantial juxtaposition thereto such that is it positioned adjacent to the sprayer head 12. In the illustrated embodiment, the device for affixing a workpiece to the support structure 16 comprises a vacuum or suction device, such as a plurality of suction cups 24 forming a bed, and a support strut. Each suction cup 24 is preferably slidably mounted to the adjacent support structure 16, and thus may be adjusted for affixation to an appropriate portion of the workpiece (preferably, a planar (non-embossed) portion to ensure that a secure bond is established). The use of a vacuum or suction device is preferred to the use of mechanical fasteners, such as clamps or the like, since it provides stable support for the workpiece without interfering with the painting operation. Moreover, the use of a vacuum or suction device comprised of plural components, such as suction cups 24, helps to prevent the unintended or accidental repositioning of the workpiece on the workpiece support structure 16 during a painting operation.

It should be appreciated that any of a number of known CNC controlled devices may be employed to support and direct movement of the sprayer head 12.

However, as noted above, in a preferred embodiment of the invention, a gantry-style robot capable of moving in up to six axes is utilized. The gantry 14 forming a part of the robot is depicted in greater detail in Figure 2, and includes motive devices for moving the sprayer head 12 along at least an X-axis, a Y-axis, and a Z-axis relative to the workpiece support structure 16. The gantry arm 14 includes a first motive device 28 for positioning the sprayer head 12 along a Y-axis. The gantry arm 14 further includes a second motive device 30 (which is actually comprised of two motive devices, one positioned on each longitudinal side of the support structure 16 as shown in Figure 1b) for positioning the sprayer head 12 along an X-axis. Finally, the gantry arm 14 includes a third motive device 32 for positioning the sprayer head 12 along a Z-axis. Motive devices 28, and 32 are shown in greater detail in the drawing included as Figure 2.

Specifically, at the left upper portion of Figure 2, the first motive device 28 for positioning the sprayer head 12 along the X-axis is shown as including a drive mechanism comprised of a motor 28a for driving an endless belt 28b that in turn frictionally engages the periphery of each of a pair of pulleys 28c. The pulleys 28c are connected to axles (not numbered), which in turn carry wheels 28d. When the motor 28a is thus actuated in either direction, the wheels 28d roll along an adjacent track member of the gantry 14 in a corresponding direction, and thereby move the sprayer head 12 to and fro along the Y-axis. A cover may also be provided to prevent outside structures from interfering with the operation of the drive mechanism.

Still referring to Figure 2, movement along the Z-axis is effected by the third motive device 32, which includes a drive mechanism comprised of a linear actuator, such as a ballscrew assembly 33 including a motor 33a. This ballscrew assembly 33 engages and moves a support arm 34 coupled to the sprayer head 12 toward and away from the support structure 16 and, hence, the workpiece. In particular, a support arm 34 includes a pair of C-shaped receivers 34a that engage corresponding tracks 35c positioned on an adjacent support plate 35 (which in turn may include channel portions for slidably engaging a support structure extending along the X-axis adjacent to the gantry 14). Hence, when the motor 33a forming a part of the ballscrew assembly 33 is actuated in either direction, the arm 34 is moved toward or away from the stable support structure 16 and thus the workpiece.

In Figure 3, it is noted that a spring-biased pin 29 is shown for coupling

the motive device 28 to the plate 35a. The motive device 28 also includes channels 28e that engage corresponding tracks 35c on the plate 35. Using this arrangement allows for the motive device 28 to move along the tracks 35c to overcome the biasing force provided by the spring-loaded pin 29. This facilitates movement of the wheels 28a relative to the plate 35 for placement over the track member 28, as well as to keep them in engagement as the robot traverses the workpiece. The spring also provides a limited shock-absorbing function along the Z-axis.

Referring back to Figure 1b, the second motive device 30 at the proximal end of the gantry 14 is shown as being similar in construction to the first motive device 28, with the wheels (not shown) being rotated by a motor 30a. The wheels roll along a second track member (not shown) to move the sprayer head 12 to and fro along the X-axis. A similar- spring-loaded arrangement may be provided for facilitating the placement of the corresponding wheels (not shown) over the second track member. A second, substantially similar motive device 30 is also provided at the distal end of the gantry 14 (see Figure 1b). As is well-known in the art, power for these motive devices may be supplied from a remote location by "e-chains" (not shown) with links that articulate as the sprayer head 12 or gantry 14 traverses along the X and/or Y-axes, respectively.

It will be appreciated that inclusion of these motive devices 28, 30, 32 allow the sprayer head 12 to be positioned at any desired location along the X and Y-axes relative to a workpiece supported on the support structure 16, as well as along a Z-axis to a desired height above the workpiece. Instead of the arrangements described above, movement of sprayer head 12 (supported by gantry 14) by first motive device 28, second motive device 30, and third motive device 32 may be effected by any known structures, such as rack and pinion gearing and belt drives or ballscrews, leadscrews, and the like. Similarly, motion of the various positioning means may be controlled by known devices such as servomotors, stepper motors, pneumatics, hydraulics, and the like. The means chosen will likely depend on the particular application in which the robot is used.

The sprayer head 12 may also be rotated along three additional axes to maximize its flexibility in performing the painting operation. To do so, as shown in Figure 4, the system includes a fourth motive device 36 for rotating the head up to 90 degrees, thereby facilitating the painting of portions of the workpiece oriented in parallel

to the plane of the X and Y-axes. A fifth motive device 38 is also provided for rotating the sprayer head up to 360 degrees, thereby allowing the angle of the spray nozzles 12a to be kept in a perpendicular orientation to the axis along which the paint is being applied. Advantageously, the added ranges of motion provided allow for the painting of, for example, an inner surface of an embossment on an embossed workpiece or a sidewall of the workpiece projecting in a plane parallel to the Z-axis. It will be appreciated that the system of this invention therefore allows automated painting of both two-dimensional planar surfaces and three-dimensional embossed surfaces without necessitating manual reconfiguration or re-calibration.

Arrangement of sprayer nozzles 12a in one embodiment of the multiple-axis sprayer head 12 forming a part of the system 10 of this invention is depicted in greater detail in Figures 4-6. As noted above, the sprayer head 12 preferably includes a plurality of spray nozzles 12a for directing the flow of paint onto a workpiece. In such an embodiment, a sixth motive device 42 may be included, thereby allowing a selected one of the spray nozzles 12a to be aligned to a known "home" or zero position relative to the work piece. A protective hood may also be provided to reduce introduction of dust or other debris into the sprayer head 12, as well as to assist in capturing any errant or reflected paint spray.

With reference to Figures 5 and 6, the fourth, fifth, and sixth motive devices 36, 38, and 42 that may form a part of the system 10 for rotating the sprayer head 12 about different axes are illustrated in detail. In the bottom portion of Figure 5, the fourth motive device 36 for rotating the sprayer head 12 along a 90 degree arc relative to the Z-axis and about the X-axis is shown as including drive mechanism. This drive mechanism includes a motor 36a having a shaft that is coupled to a first pulley 36c (not shown) that drives an endless belt 36b (not shown). A second pulley 36c (not shown) is coupled or fixed to one end of a pivot pin 36d that extends through a hinge structure 36e (not shown) formed between a plate 37 for supporting the sprayer head 12 and a plate (not numbered) forming a part of the fifth motive device 38. Hence, when the motor 36a is activated, the entire sprayer head 12 is caused to pivot toward and away from the workpiece support structure 16 about the X-axis and along a 90 degree arc to allow for the painting of portions of the workpiece oriented in parallel to the plane of the X and Y axes. A cover C is also provided for covering the belt 36b and pulleys 36c to prevent outside

interference. An adjustable belt tensioner (not numbered) may also be provided to ensure that the proper tension is achieved in belt 36b.

Moving now to the top portion of Figure 5, the fifth motive device 38 includes a drive mechanism having a motor 38a. The shaft of the motor 38a carries or is coupled to a first pulley 38b that engages an endless belt 38c. The belt 38c passes through a pair of spaced bearings 38d (which provide tensioning) and is entrained over and frictionally engages the periphery of an adjacent pulley 38e. The pulley 38e is in turn coupled or locked onto the periphery of a support 38e that includes an upstanding cylindrical portion and a portion of the hinge 36e to which the plate 37 is pivotably coupled. Hence, when the motor 38a is actuated, the endless belt 38c moves to rotate the pulley 38e, which in turn rotates the support 38f. Since the support 38f is coupled to the plate 37 supporting the sprayer head 12 via hinge 36e, it rotates the sprayer head 12 about the Z-axis up to 360 degrees. A tubular bushing is also provided over the support 38f, and is prevented from moving along the Z-axis by a plate 38g supporting the drive mechanism. The underside of this bushing provides a bearing function for an inwardly projecting portion of the support arm 34. A cover may also be provided for preventing interference with the components of the drive mechanism of the motive device 38.

Figure 6 is an exploded view of the sprayer head 12, including the nozzles 12a, and also illustrates one possible embodiment of a sixth motive device 42. This motive device 42 includes a drive mechanism having a motor 42a, the shaft of which projects through an aperture in plate 37 into engagement with a pulley 42b. An endless belt 42c is entrained over and frictionally engages the outer surface of this drive pulley 42b, as well as a second, adjacent driven pulley 42d. A cylindrical portion 37a projecting from the plate 37 provides a bearing surface for the pulley 42d, which is coupled to a structure 42e for supporting the nozzles 12a. Means for locking the support structure 42e to the projecting portion 37a are also provided, including a locking ring 42f. Hence, when the motor 42a is actuated, the spray nozzles 12a are caused to rotate about the centerline axis of the projecting portion 37a, which is generally parallel to the Y-axis when the sprayer head 12 is in the nominal position. Channels (not numbered) may also be provided in the support structure 42e that engage camming structures, such as pegs (not shown), that serve to define the maximum arc through

which the sprayer head 12 may rotate about the Y-axis.

A cover C having an aperture for allowing the support structure 42e to pass is also provided.

It is further noted from Figure 6 that each spray nozzle 12a is pivotably supported by a finger 41 coupled to the support structure 42e. The end of each spray nozzle 12a opposite the nozzle portion includes a male receiver 40 for receiving a hose or tube (not shown) that supplies paint under pressure to the nozzle 12a. An adjustable thumb screw may also be provided for fine-tuning the positions of the nozzles 12a relative to the Z-axis. Each hose may be coupled to a single paint source, or alternatively to a multiple position, solenoid operated valve (not shown). The valve is in turn coupled to multiple paint sources. As a result, color changes can be made by completing a nozzle cleaning operation (preferably automatic) and then changing the position of the valve. Both operations may be computer controlled. For example, the computer system could control the position of the valve by taking a 5vdc computer signal, which represents a specific solenoid, or grouping of solenoids. That 5vdc signal could switch an optically isolated relay, which would control 24vdc, 48vdc, 120vac or 240vac. This increased power would then switch on and off with the 5vdc signal, supplying enough power and ample voltage to actuate the solenoid valve.

The system 10 is also capable of determining the positioning of the workpiece and for calibrating the painting device to the position of the workpiece. In a presently preferred embodiment, the determination is made in a non-contacting fashion using a first triangulating laser (not shown) oriented so that the beam of the laser is aimed exactly along the axis of rotation of the fifth motive device 38 (i.e., perpendicular to the plane of the workpiece). A second triangulating laser (not shown) is located substantially adjacent to the first triangulating laser (not shown), but is oriented such that its beam projects at a 45 degree angle. The first and second triangulating lasers are calibrated such that the intersection of the two light beams represents the desired distance of the sprayer head 12 from a particular workpiece. Accordingly, when the sprayer head is positioned too near or too far from the workpiece, two light points are visible, instead of one.

As perhaps best shown in Figure 4, the sprayer head 12 also includes a cutting assembly. The cutting assembly 50 may include a cutter element (not shown)

carried on a support 51. The cutter element is preferably adjusted to be positioned at a nominal height such that it makes contact with an upper surface of the workpiece when the sprayer head 12 is moved to a certain position along the Z-axis. This contact allows the cutter element to cut a structure on the surface of the workpiece, such as a previously applied masking. The cutter element is preferably spring biased toward the workpiece (note springs 52 in Figure 4) to ensure that the correct amount of cutting force is evenly applied to remove the masking, without damaging the workpiece.

Any of a number of computer devices suitable for controlling CNC machines maybe adapted to control the system of this invention. In a presently preferred embodiment, a dual control arrangement is utilized wherein the predetermined job to be performed is input in a centralized system, and transferred to a machine-side controller. The machine-side controller controls such device-specific tasks as completion of the painting tasks, cutting tasks, the automated changing of paint colors, and cleaning of spray nozzles and paint feeder lines (such as at a selected remote location relative to the support structure where the paint remaining in the lines and any cleaning fluid is collected for disposal).

As developed further below, the centralized control may comprise software that develops instructions for a particular painting job and provides them to the CNC machine control on the basis of a series of questions which a user must answer (often referred to as a "wizard" by those of skill in the art). For example, the user is first asked to assign colors to particular spray nozzles 12a (which may require the proper mechanical hookup to one or more remote paint sources using multiple position valves, as previously mentioned), and indicate whether the design to be painted is to be cut from a pre-applied masking, such as using the cutting assembly 50. Next, the user may be prompted for more specific information regarding the painting operation, such as: (1) the number of coats of paint to be applied for specific categories of color (e.g., for white, for light colors, and for dark colors); (2) the selection and placement of a geometric shape for painting (including an alphanumeric character); and (3) the selection of a painting pattern. As an example, after the color and the number of coats are selected, a shape may be outlined by the user, and then an indication as to whether it is to be painted solid (island fill) or painted in a hatch pattern may be made. Finally, the centralized controller brings up a screen visualizing the object

to be painted and the selection of colors chosen. The user may then select a particular pattern on the overall design being painted, assign a color, and if necessary assign an emboss depth to ensure accurate painting of all surfaces of an embossed workpiece regardless of location.

The machine-side controller automatically brings up painting jobs in the order assigned by the centralized controller. The user inputs specific lists of paint colors to individual spray nozzles 12a, and assigns the order in which multiple spray nozzles 12a will be activated. The user may control numerous functions of the painting system 10 using the machine-side controller, such as manual movement of sprayer head 12 to desired coordinates relative to a workpiece, selection of a particular spray nozzle 12a, rotation of sprayer head 12 by the fifth motive device 38, purging paint lines and/or switching colors, cleaning spray nozzles 12a, controlling rate of paint and driving fluid flow, and the like. In a presently preferred embodiment, the machine-side controller comprises a standard personal computer with touch-screen interface.

Also disclosed is a manner of positioning of the sprayer head 12 relative to a workpiece and calibrating its relative position to allow computer controlled application of paint at desired locations, thereby allowing automated creation of even the most complex designs with limited user input following the initial calibration and programming steps. The first step is to place coordinate markers at predetermined locations on the workpiece. In one example, at least a first and a second dimple are placed at predetermined locations, such as on the border of a workpiece. This may be achieved by a variety of processes, such as by forming the dimple during a vacuum forming fabrication process. Next, an operator manually orients the sprayer head 12 over the first dimple using the machine-side controller previously described. Using the height-adjustment feature described above, the user then adjusts the sprayer head 12 along the Z-axis until the desired distance from the workpiece is reached, i.e., when the beams of the first and second triangulating lasers meet to form a single point. If necessary, the operator may then manually adjust the sprayer head 12 along the X and Y-axes as needed to ensure that the light point formed at the vertices of the two laser beams is directly centered over the first dimple. The measured Cartesian coordinates of the first dimple are then transmitted to the controller. The process as

described above is then repeated over the second dimple.

Next, the controller creates a right triangle from the acquired Cartesian coordinates of the first and second dimples. Once acquired, this right triangle is compared to a theoretical right triangle provided by a pre-programmed digital job corresponding to the painting job being completed. The theoretical right triangle contained in the preprogrammed digital job is oriented substantially in parallel to the Cartesian X and Y axes created by the computer controller. The controller then rotates the theoretical right triangle contained in the pre-programmed digital job to align its 90 degree angle to that of the acquired right triangle (which is developed from the acquired Cartesian coordinates of the dimples on the workpiece). The computer controller also compares the Cartesian coordinates of the two non-90 degree vertices of the theoretical and acquired right triangles, and calculates a correction factor. This correction factor may be applied to all linear axis movements to compensate for shrinking or expansion of the workpiece material in comparison to the expected size of the workpiece as programmed into the computer controller. Formulae for calculating these correction factors are known in the art, and are noted below.

This invention further provides a method of painting a workpiece such as a sign utilizing the painting system 10. The method of this invention is suitable for automated painting of either a flat, substantially two-dimensional surface, or an embossed surface providing a three-dimensional area. In one embodiment of the method of this invention, the first step comprises calibration of the painting system 10 as described above. Then, for more complex designs, a masking or removable coating may be applied to the entire surface of the workpiece, such as through a first spray nozzle 12a. Any suitable masking substance capable of spraying, but easily removable from the surface of the workpiece, may be used. Alternatively, the masking may be pre-applied to the workpiece, either automatically or manually, including as part of the workpiece fabrication process. The desired pattern to be painted on the workpiece is then cut into the masking or coating using the cutter element of cutter assembly 50, in accordance with the commands of the pre-programmed digital job.

Next, portions of the pre-cut masking coating covering the area of the workpiece to be painted are removed. This may be accomplished manually, or by any suitable automated system. The desired color is then applied through a selected spray

nozzle 12a. This process is repeated until the desired design has been painted onto the workpiece. In a preferred embodiment, the order of application is from darkest colors to lightest colors, with the final application being white for purposes of contrast. However, any desired order of color application may be programmed. As noted above, the sprayer head 12 is capable of painting both flat, planar surfaces of the workpiece in two dimensions (X and Y-axes) and embossed surfaces in three dimensions (X, Y, and Z- axes).

It should be appreciated that the method and system of this invention may be adapted for painting standard, flat workpieces, which will either remain flat or be embossed at a later time. The method of painting a flat workpiece requires strictly controlling the paint and the pressure or flow of a driving fluid (pressurized air) as well as the distance of the selected spray nozzle 12a from the workpiece to maximize the pattern of the paint applied to a particular design. As noted, the painting system 10 of this invention is well-suited to this application.

For workpieces to be first painted, and then embossed by any means such as a vacuum molding machine and a die. it is known that the embossing process results in distortion of the face of the workpiece. As will be appreciated by those skilled in the art, it is possible to estimate the extent of distortion of the workpiece during embossing, and to program the controller to automatically compensate for this distortion in the digital paint job.

Next, a description is presented of how the described system and method would work in a typical case of painting an embossed face. First, a digital job file is created from artwork or from a series of closed, nearly closed shapes or other geometric entities (lines, arcs, circles, polygons, points, curves and splines), drawn to scale, and sent to a CNC or manual cutting department. A mold is created for the purpose of forming the face into a uniquely embossed sign face. Then specific paint requirements, such as individual colors, type of spray pattern, whether or not masking material will be applied, and other pertinent data would be applied to these shapes for the purposes of predefining the movement and action of the machine.

An unpainted sign face made of Acrylic, Lexan or some other semi-rigid material is laid upon the suction cup bed of the machine. The operator proceeds behind the bed to adjust the suction cups to the face of the sign to hold it firmly in place. An aluminum extrusion with a linear slide holding the suction cup is then

positioned to a flat area of the sign face, yielding adequate holding power to the face. The vacuum is manually or electronically applied to that portion of the face. This is repeated until adequate holding power is applied to the face.

The operator using a jog control for the X, Y and Z axes jogs the head over a dimple created in the face by the vacuum forming mold. Two laser pointers, one pointing straight down from the center of the rotation of the Theta axis, and another which is located a few inches from it along the 0° axis, pointed at a 45 angle toward the first, will create a "laser triangle." This triangle will be invisible except for two points, which are created from the interruption of the laser where it hits the inside surface of the sign face. These points will move closer together or farther apart as the Z axis of the machine is jogged up or down. The machine operator manually jogs the Z axis until the laser pointers appear to meet and make one point, the vertices of the "laser triangle." Once the vertices are established the operator may need to reposition the X and Y axes until the vertices appear directly centered over the dimple in the sign face. A signal is given to the computer control, indicating that the head (XYZ axis) is positioned over dimple 1 or 2, specifically. The same process is then performed to locate the other dimple. This data will provide information to the computer control as to the location of the material with respect to the bed, since the material may not always have a referenceable edge or edges. Furthermore, the alignment of the two lasers so that they make one will provide to the computer control a physical distance between the material and the paint heads. This distance where the two lasers become one, will be predetermined and programmed into memory of the computer control for the purposes of defining the Z-axis location of the paint heads relative to the material to be painted.

The computer will compare the collected Cartesian locations of dimple one and dimple two to the Cartesian locations of the digital job. A right triangle would be created between each set of points, collected and that provided by the digital job file. The digital job file's right triangle, with the edges created along the internal angle 90°, would run parallel to the Cartesian X and Y axes created by the computer control, respectively. The right triangle created from the acquired points would most likely not run true to the physical X and Y axes of the machine. Therefore, the digital job file would be rotated to correspond with the physical job file upon the

vertices of the triangle created during triangulation (90° vertices), for the purpose of aligning the two created triangles. Furthermore, the Cartesian location of the two other vertices of the triangle (non-90° vertices), would be compared to come up with a correction factor to be applied to all linear axis moves, whether independent or coordinated with another axis (axes), and used to compensate for the shrinking and expanding of the physical sign face material. The following represents one formula for this:

(C-a)/(C-A)=X, the multiplier for the X-axis travel
(C-b)/(C-B)=Y, the multiplier for the Y-axis travel
where
"A" = the physical Cartesian location of Dimple 1;
"B" = the physical Cartesian location of Dimple 2;
"a" = the Cartesian location of the digital Dimple 1;
"b" = the Cartesian location of the digital Dimple 2.
"C" = the Cartesian location of the 90° vertices
created when the points are triangulated.

The software for painting the sign face consists of two parts, the office system and the machine-side control. The office system is responsible for setting up the job, applying various paint techniques, assigning colors to various objects and between various objects, respectively assigning "Z" locations of the various embossed surfaces for accurate paint control, and assigning the order in which paint will be applied.

The machine-side control actually brings up the job, calibrates and compensates the job, as described earlier, and controls tasks such as the automatic changing of colors and cleaning of paint guns and lines.

The office system will use a parametric method of defining the job known as a software wizard. The wizard will prompt the user for the file formats, such as, but not limited to, DXF/DAT/JOB file with a preview of the job file. The parametric software wizard will proceed accordingly:

1. First, the wizard will ask what colors should be used and from what head they should be sprayed. This should be in the form of a chooser box. A list of colors from a Color Database would appear on the left of the screen. A series of

numbered edit boxes, which represent guns 1 – 6, would appear on the right. A check box would indicate whether the operator wants the face to be knifed. There should be an edit box which asks for a total number of coats for light colors, white, and dark colors.

2. The next screen will show several dialogues below three columns labeled white, light colors, and dark colors, one for each coat for each color. A list box with the 6 colors chosen for this job will be listed. The user should drag these colors to a specific column: dark, light, or white. A check box also would be available to instruct the system to coat all white. This will paint the entire back white upon completion.

3. The next screen will show the colors listed as column headers. Under each header will be 6 drop-down boxes. A vertical header will label these P1-P6. Each drop-down box will have the following information: None, Outline, Island, Hatch. These correspond to the process of outlining a shape, island fill pattern, and hatch fill pattern. Three edit fields will ask the stroke width for each of the above.

4. The next screen will show the colors in a list from dark to light (CMYK values added together, using a multiplier of, e.g., 5 for B, 2.5 for M, 2 for C and 1 for Y.) These values will be stored in the color database. The user may rearrange these. An edit box will ask the depth of the pan. A finish button will then appear.

5. When finished the software will zoom to the extents of the DXF file selected. A modeless dialogue with the colors to be used in the job will appear. The user will be put into a tool which will allow him to choose an object, assign a color from the colors selected, and assign an emboss depth. The colors will be shown by the color of the island and hatch toolpaths, but later the operator can use FIST to triangulate the inside of the letter. The default depth will be whatever the pan depth was set to. A memo field also could be created by the office system and would be displayed when the job is first brought-up machine side.

Following is a description of how the machine-side software would run. A job list created by the office system will run modeless. When the next job is clicked on it will automatically popup and zoom to its extents.

1. Upon this job opening, the following dialogues will popup: Paint color list to load in each respective paint gun (p1-p6) in the order which they will be sprayed.

2. A series of buttons will need to be added to the screen: Home Spray heads, Home Rotation, home XY, Home Z. Additionally, there should be buttons to purge the lines and switch colors, buttons to manually run a single shape again, with a zigzag or island pattern. Temporary data would be set.

3. The system contains a control to manually perform functions such as jog, clean specific paint heads, change colors in specific paint heads or prime paint lines for each specific paint head.

4. The machine operates using a touch screen interface and PC based control.

The machine, upon being calibrated and a job file being run, will paint multiple colors from darkest colors to lightest colors, where the final color being applied is white, covering the entire back surface of the sign. In some cases, a mask coating applied through one of the spray guns will be applied prior to any or little paint being applied. This coating will then solidify into a paint mask and the knife head attached to the head assembly would be deployed to cut the outline between colors. An operator or other manual or automated system would then peel away the appropriate areas identified on the screen, where the next color would then be applied. This method would continue until all of the mask is removed, the back of the sign is painted entirely white, and the sign is completely painted.

Another method of painting faces is to paint them in the flat state. Two types of faces will be painted in this format, those which will remain flat and those which will later be embossed.

In order to accurately control the quality of the flat face finish, a pattern of rotating the head, reducing the paint and air flow and lowering the paint gun closer to the surface around the outside perimeter and corners is necessary. This enables the system to create a tight "crisp" line around the geometry being painted. Again, darkest colors are painted first, then lighter until the final coat over the entire surface is white.

In some cases, a mask coating applied through one of the spray guns will be applied prior to any or little paint being applied. This coating will then solidify into a paint mask and the knife head attached to the head assembly would be deployed to cut the outline between colors. An operator or other manual or automated system would then peel away the appropriate areas identified on the screen, where the next color would then be applied. This method would continue

until all of the mask is removed, the back of the sign is painted entirely white and the sign is completely painted.

When a face is painted where the face will later be embossed using a vacuum molding machine and a die, the painting of the face must be distorted to accommodate the distortion of the plastic caused during forming. This distortion can be calculated and the geometry of the job file can be "run through" an algorithm to compensate for it.

The foregoing description of several aspects of the invention has been presented for purposes of illustration and description. The embodiments described are not intended to be exhaustive or to limit the invention to the precise form disclosed. Obvious modifications or variations are possibly in light of the above teachings. For example, while the workpiece is shown as a sign for purposes of the preferred embodiment, it should be appreciated that the workpiece may comprise any structure requiring painting (although structures having substantially planar surfaces, with or without embossments, are preferred). Also, stops, such as upstanding pegs or an L-shaped channel, may also be strategically positioned at the ends of the support structure 16 to limit the motion of the robot as it traverses relative to the workpiece (see, e.g., Figure 1a and note X-axis stop 19). The embodiments described were chosen to provide the best illustration of the principles of the invention and its practical application to thereby enable one of ordinary skill in the art to utilize the invention in various embodiments and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the invention when interpreted in accordance with the breadth to which it is fairly, legally, and equitably entitled.

I. CLAIM:

1. A painting system, comprising:

a painting device including a sprayer head having one or more nozzles;

a plurality of motive devices, each for moving the sprayer head and/or the nozzles about or along a corresponding axis; and

a stable structure for supporting the workpiece relative to the sprayer head.

2. The painting system according to Claim 1, further including a workpiece in the form of a substantially planar sign, with or without embossments.

3. The painting system of Claim 2, wherein the plurality of motive devices comprise:

a first motive device for moving the sprayer head along a first axis parallel to a plane of the workpiece;

a second motive device for moving the sprayer head along a second axis parallel to the plane of the workpiece.

4. The painting system of Claim 3, wherein the plurality of motive devices further comprise:

a third motive device for moving the sprayer head along a third axis perpendicular to the plane of the workpiece.

5. The painting system of Claim 4, wherein the plurality of motive devices further comprise:

a fourth motive device for rotating the sprayer head about said first axis;

a fifth motive device for rotating the sprayer head about said second axis; and

a sixth motive device for rotating the sprayer head about said third axis.

6. The painting system of Claim 2, wherein the painting device includes a gantry-style robotic arm for supporting the sprayer head.

7. The painting system of Claim 2, wherein the workpiece includes a mask, and the painting device includes a cutter mechanism for cutting the mask to expose selected portions of the workpiece for painting.

8. The painting system of Claim 7, wherein the mask is applied to the workpiece by at least one spray nozzle of the sprayer head.

9. The painting system of Claim 2, further including a device for assisting in calibrating the position of the painting device relative to the workpiece, said calibration device comprising at least two light sources that generate light beams that intersect when the painting device is at a predetermined location relative to the workpiece.

10. The painting system of any one of Claims 2-9, further including a controller for automatically controlling the movement and operation of the painting device based on information previously provided by an operator.

11. The painting system of Claim 10, wherein the workpiece includes at least two indicia at predetermined locations and the controller is capable of acquiring data regarding the locations of said indicia and then determining whether a corresponding adjustment to the instructions provided by the operator is necessary to ensure that the workpiece is painted in the desired fashion.

12. The painting system of Claim 10, wherein the controller includes a computer programmed to prompt the user for information that is used to create a digital job representative of the movement and operation of the painting device.

13. The painting system of any of Claims 1-12, wherein the stable support structure includes at least one vacuum or suction device for holding the workpiece in place during the painting operation.

14. A method of compensating for variations in the position or size of a workpiece in an automated painting operation performed based on a series of instructions or information provided by a user, comprising:

sensing a location of a first indicia on the workpiece;

sensing a location of a second indicia on the workpiece;

calculating the parameters of a right triangle from the sensed locations;

comparing the calculated right triangle to a theoretical right triangle in the provided instruction or information;

calculating a correction factor therefrom; and

applying the correction factor to the instructions or information provided by the user.

15. A method of painting, comprising:

providing a masking on a workpiece;

removing at least a portion of the masking to expose a section of the workpiece;

automatically painting the exposed section of the workpiece using a gantry-style robot.

16. The method of Claim 15, wherein the providing comprises spraying a masking substance on the workpiece.

17. The method of Claim 15, wherein the removing comprises:

cutting the masking; and

manually removing the masking from the workpiece.

18. The method of Claim 15, further comprising repeating the removing and painting with a plurality of different colors to create a complex visually pleasing design.

19. The method of Claim 15, wherein the workpiece is a sign, and the providing comprises forming the masking on the sign during the manufacturing process.

20. A method of painting a workpiece for later undergoing embossment, such as a sign, comprising:

providing instructions to a controller regarding one or more areas of the workpiece to which paint is to be applied;

providing an instruction regarding whether and the degree to which any of said one or more of said areas are to be embossed;

programming the controller to automatically adjust the size of the area to be painted at the embossment locations to compensate for distortion created during later embossing.

21. A method of painting according to a pre-programmed set of instructions, comprising:

providing a workpiece in the form of a generally planar sign;

providing a painting device including a sprayer head having one or more nozzles; and

moving the sprayer head and/or the nozzles about or along any of at least six axes in accordance with the pre-programmed instructions while selectively providing paint to at least one of said nozzles to paint the sign.

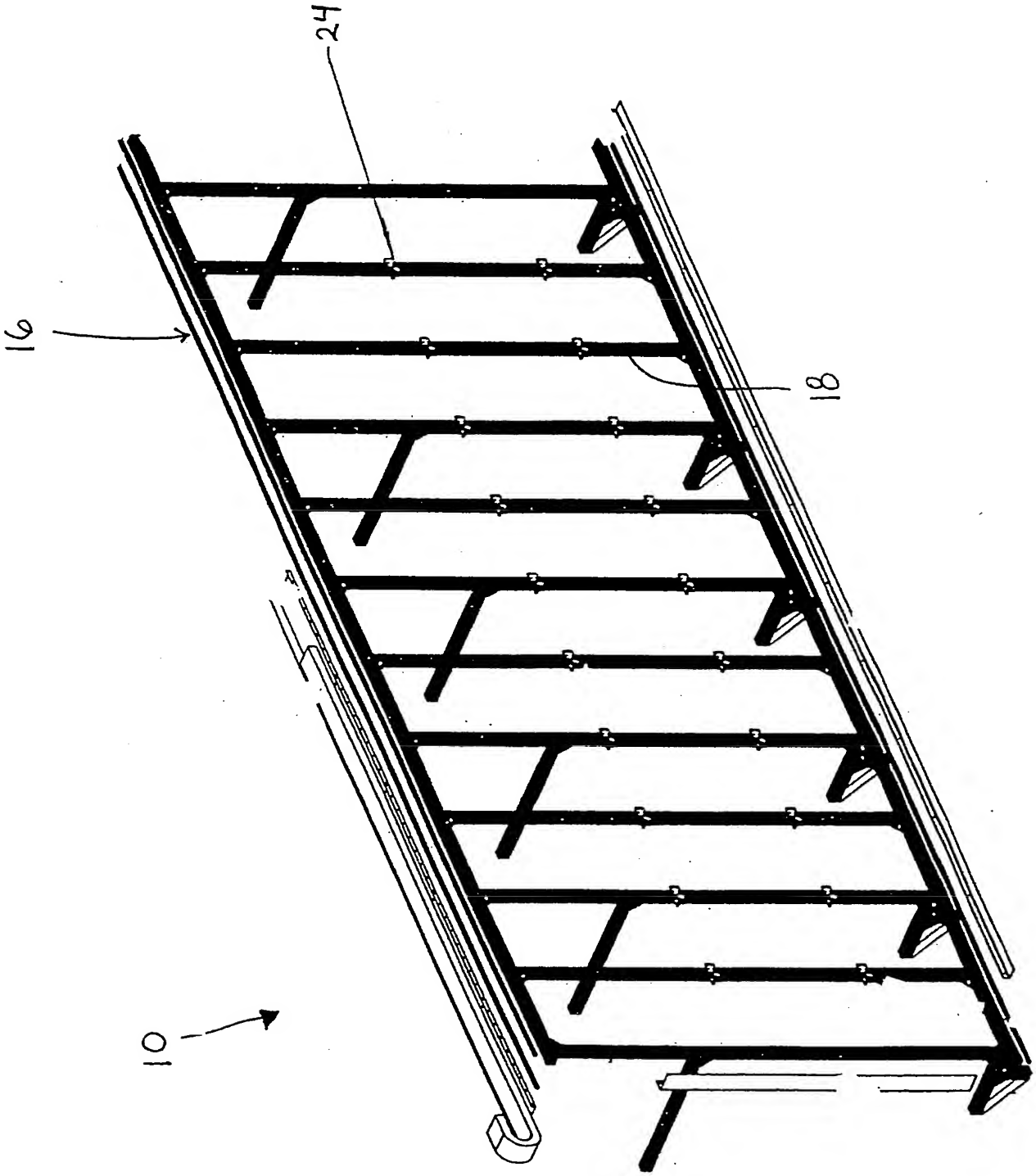

Figure 1a

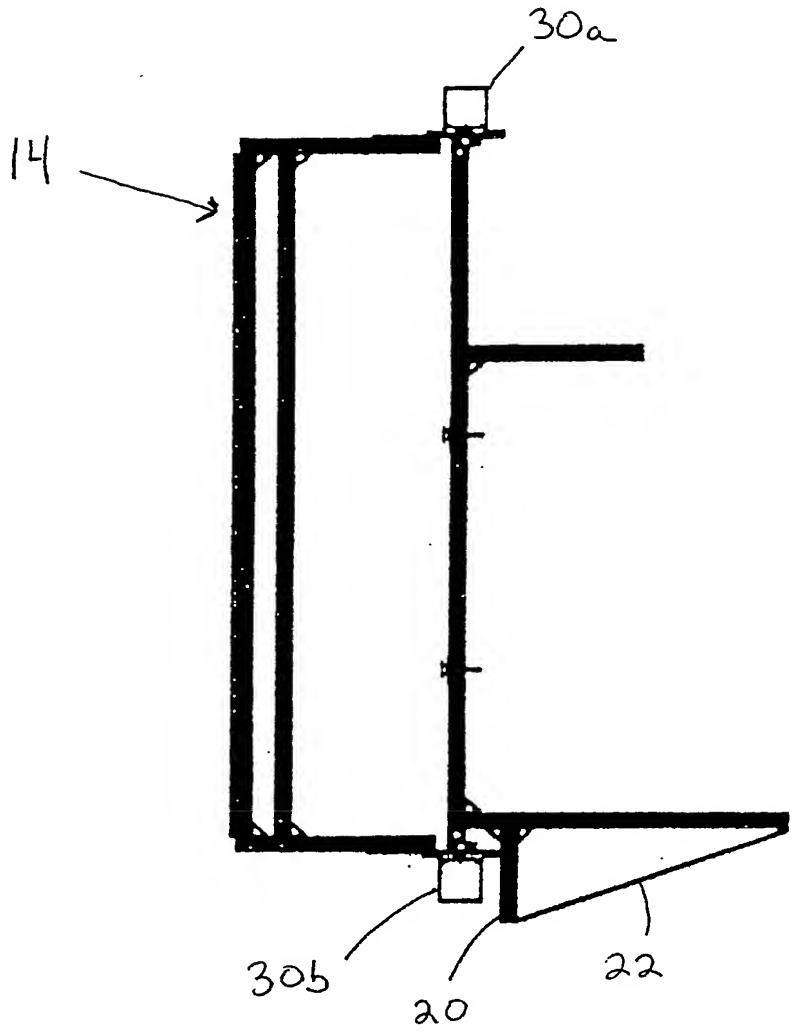

Figure 1b

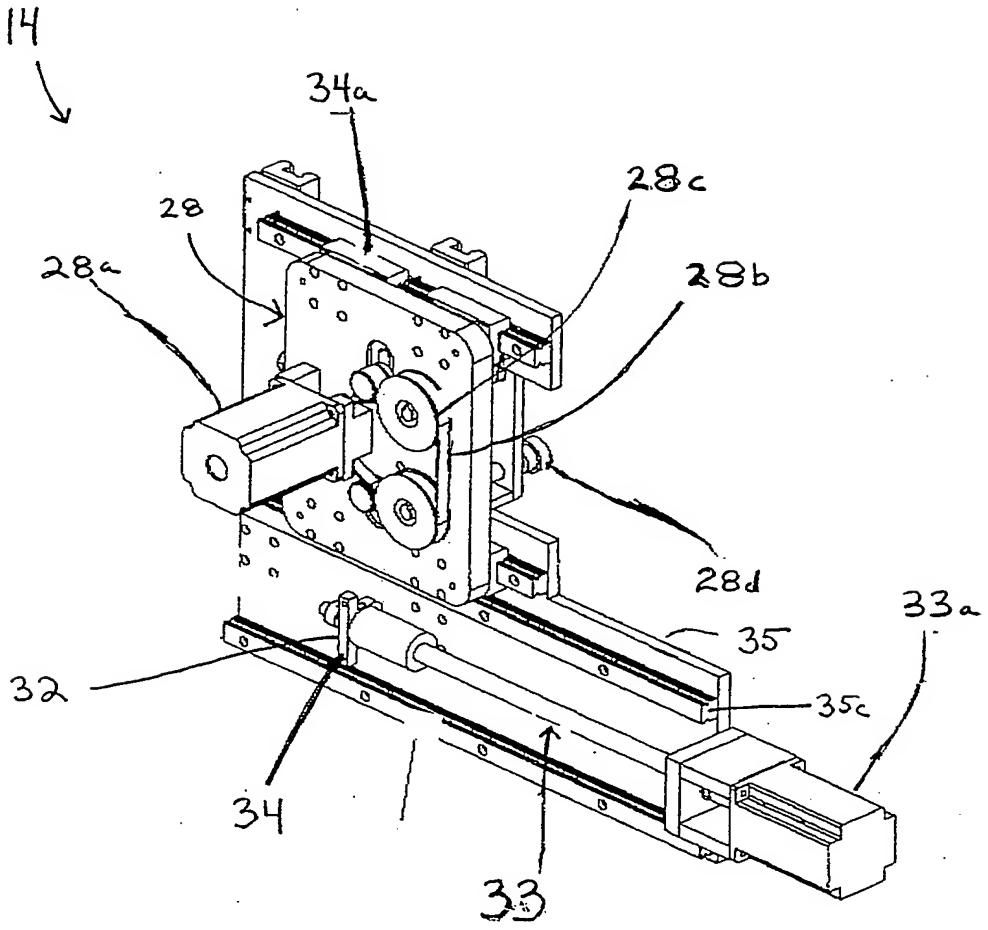

Figure 2

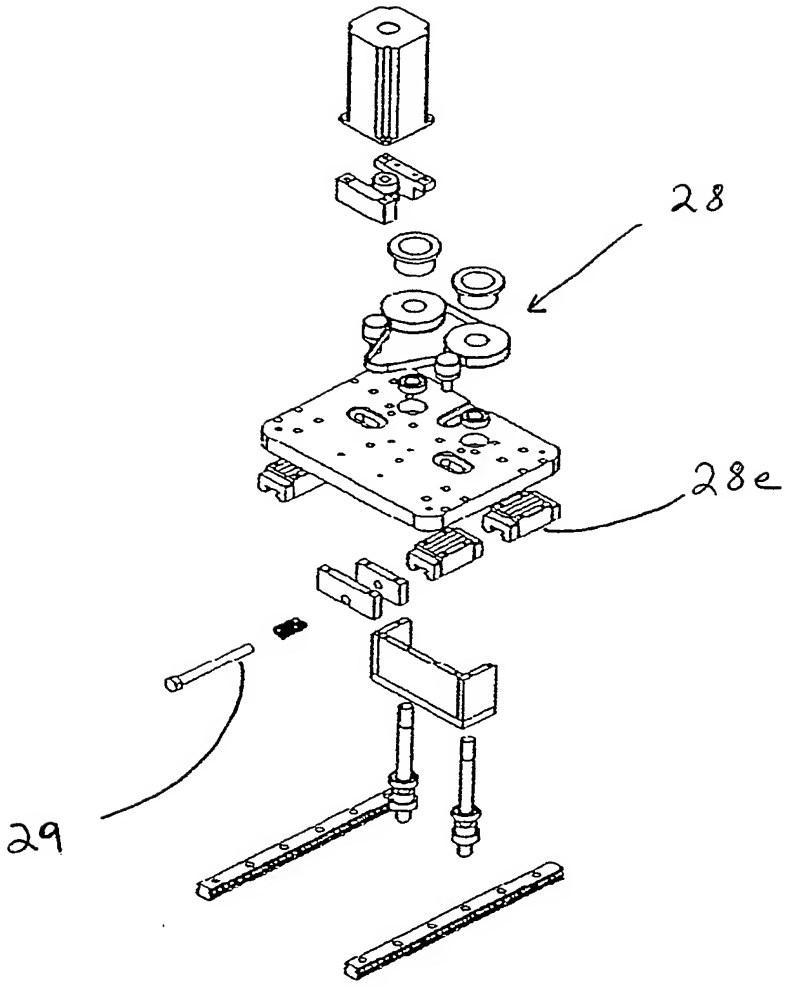

Figure 3

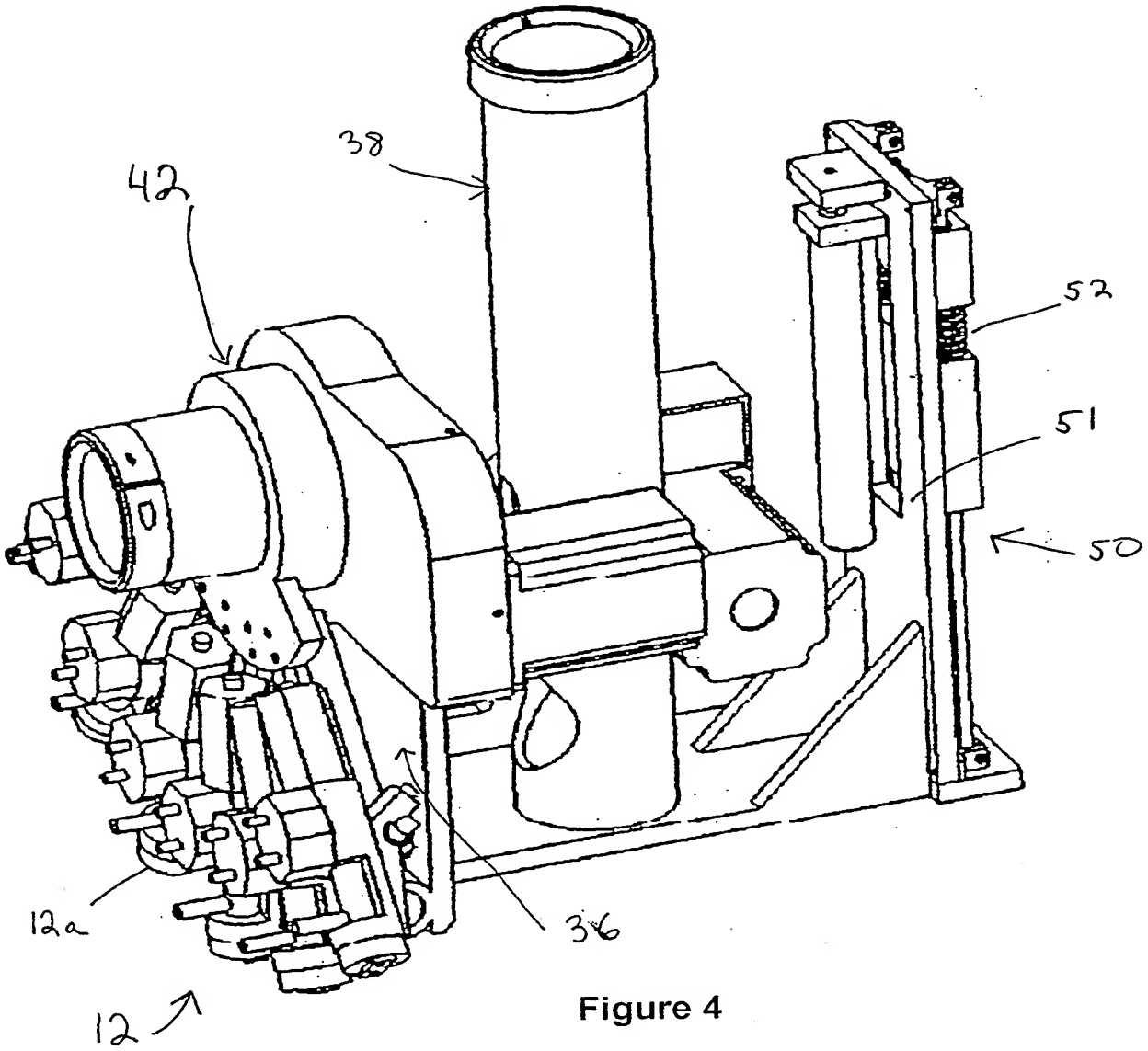

Figure 4

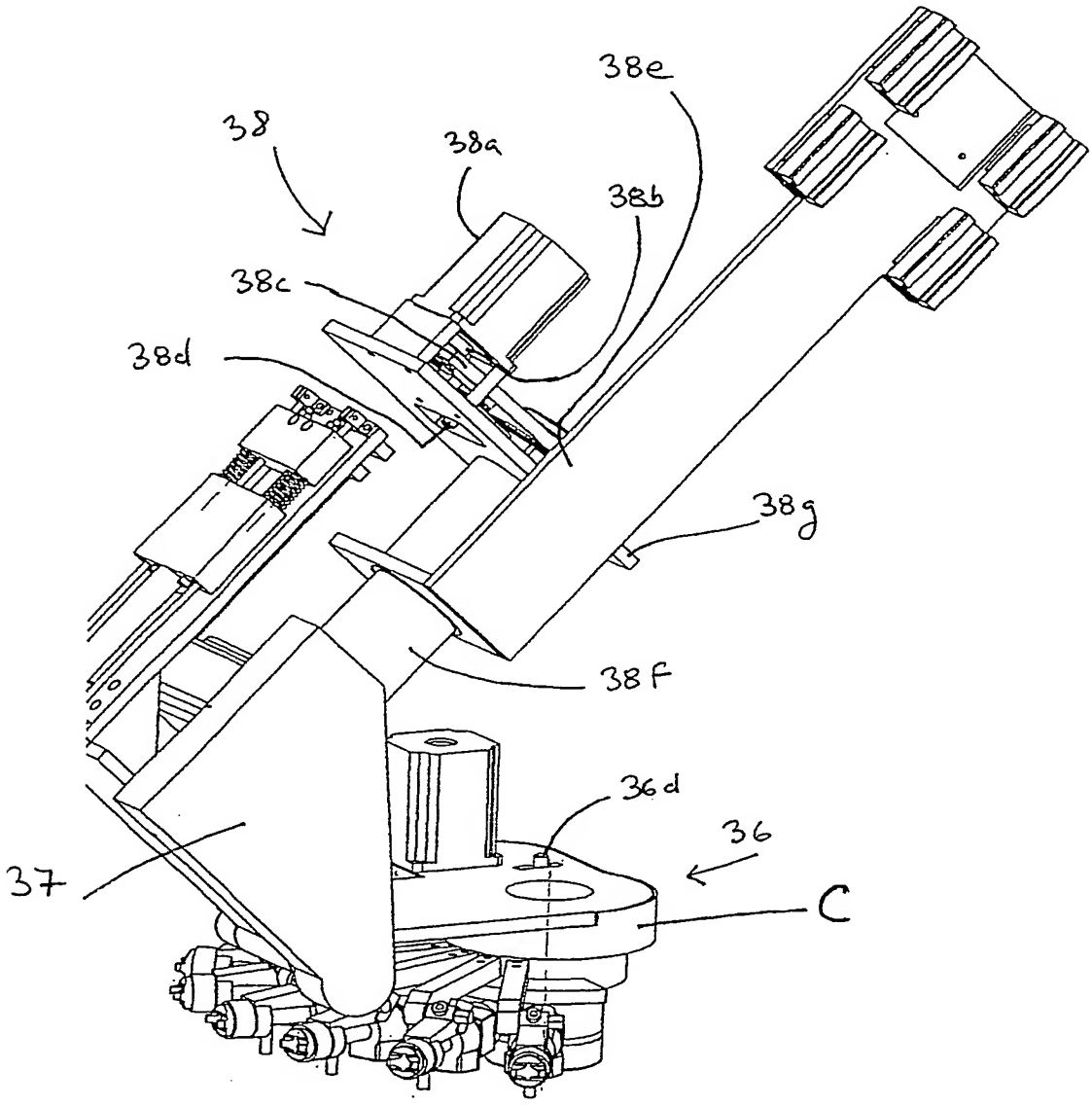

Figure 5

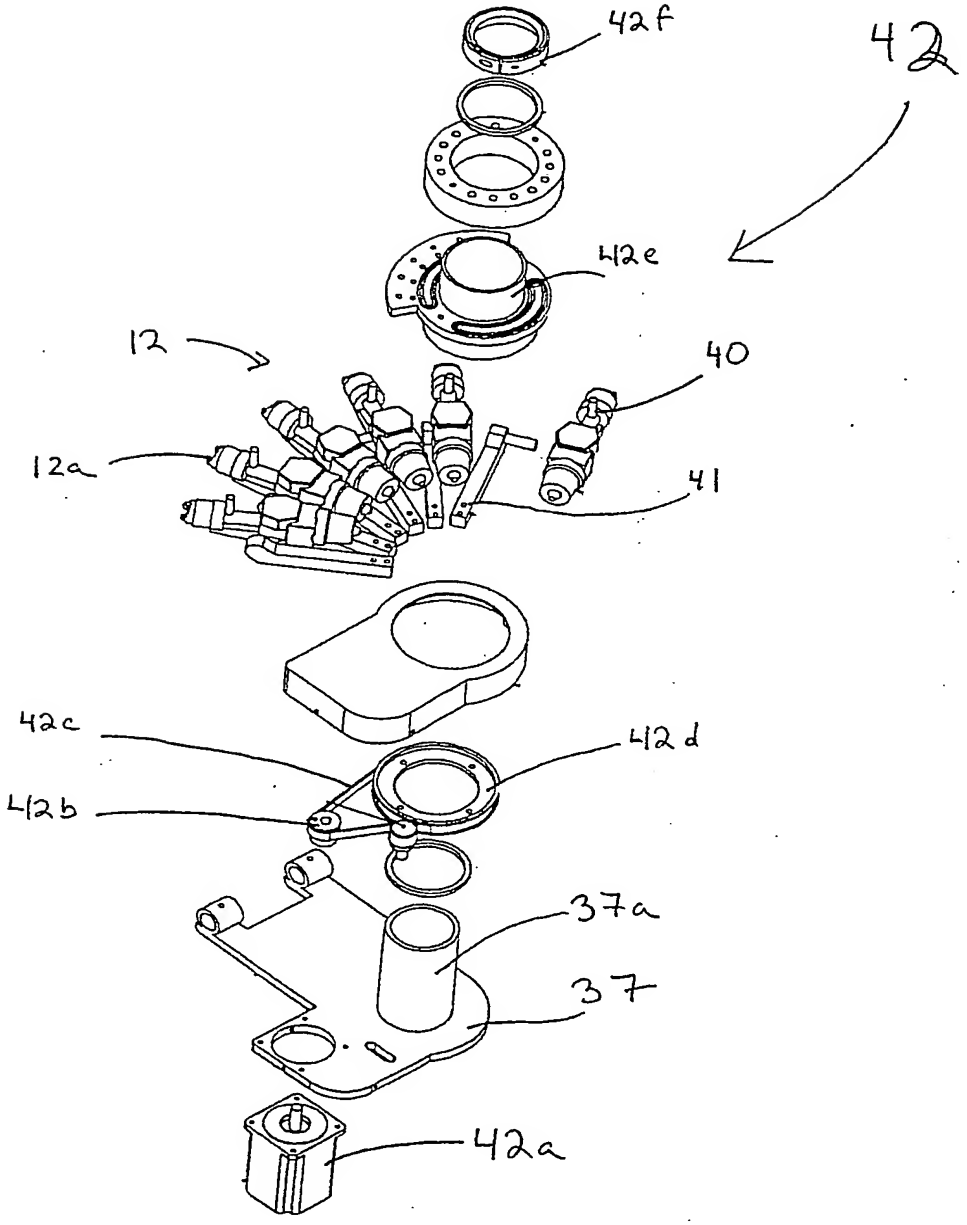

Figure 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/32389

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : B05C 11/00
US CL : 118/300
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 118/300,668,679,712;427/10,259,264,272

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,429,682 (HARLOW, JR et al) 04 July 1995 (04.07.1995), column 2, line 5 - column 15, line 66.	1-5,20,21
Y	US 6,096,132 (KAIBA et al.) 01 August 2000 (01.08.2000), column 1, line 13 - column 5, line 64.	6,10,15,19
Y	US 5,436,027 (OFFER) 25 July 1995 (25.07.1995), entire document.	7,8,15-18
Y	US 5,175,018 (LEE et al) 29 December 1992 (29.12.92), column 5, lines 46 - 68.	9
X,P	US 6,459,955 B1 (BARTSCH et al.) 01 October 2002 (01.10.2002), column 2, line 15 - column 13, line 26.	14

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 December 2002 (11.12.2002)	07 JAN 2003
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Richard Crispino Telephone No. 703-308-0661

Form PCT/ISA/210 (second sheet) (July 1998)